Peer-reviewed version available at *Int. J. Environ. Res. Public Health* **2019**, *16*, 386; doi:10.3390/ijerph16030386

Article

Health assessment of electronic waste workers in Chile: study design and participant characterization

Karla Yohannessen[1], Daniela Pinto-Galleguillos[1], Denisse Parra[2], Amaranta Agost[1], Macarena Valdés[3], Lauren Smith[4], Katherine Galen[4], Felipe Rojas[1], Richard L. Neitzel[4], Pablo Ruiz-Rudolph[1]*

[1] *Programa de Salud Ambiental, Instituto de Salud Poblacional, Facultad de Medicina, Universidad de Chile, Independencia 939, Independencia, Santiago, Chile.*
[2] *Departamento de Enfermería, Facultad de Medicina, Universidad de Chile, Independencia 1027, Independencia, Santiago, Chile.*
[3] *Programa de Epidemiología, Instituto de Salud Poblacional, Facultad de Medicina, Universidad de Chile, Independencia 939, Independencia, Santiago, Chile.*
[4] *Department of Environmental Health Sciences, School of Public Health, University of Michigan, 1415 Washington Heights, Ann Arbor, MI 48109, USA.*

Received: date; Accepted: date; Published: date

* *Correspondence: Pablo Ruiz-Rudolph. Programa de Salud Ambiental, Instituto de Salud Poblacional, Facultad de Medicina, Universidad de Chile, Independencia 939, Independencia, Santiago, Chile; pabloruiz@med.uchile.cl; phone (+56-22-978-6379)*

Abstract: Little research has been done on occupational health ramifications of informal electronic waste (e-waste) recycling work, which is increasingly common in low- and middle-income countries, and very little is known about this in high-income countries. Our study evaluated informal and formal e-waste recycling workers in Chile, which was recently recognized as a high-income country. In 2017 we recruited 78 informal recycling workers from two cities, and 15 formal e-waste recycling workers from one recycling facility. Participants completed a questionnaire and health assessment regarding their involvement in, and potential impacts of, e-waste recycling, among other measures. Participants were primarily male, middle-aged, married with children, and had worked in e-waste recycling for an average of 12 years. Participants generally reported good health status, and chronic disease prevalence was similar to the national prevalence. Workers commonly reported exposures to several occupational stressors, including mental health stressors and noise, as well as insufficient income. Occupational injuries were common and use of safety equipment was low. No significant differences were found between informal and formal workers. Informal e-waste workers in Chile face occupational health challenges. The extent to which these issues impact the health of informal Chilean e-waste workers is unclear and warrants further research.

Keywords: Electronic waste recycling; occupational health; public health; injuries; stress

List of tables

List of figures

List of supplemental tables

1. Introduction

In 2013, the World Health Organization (WHO) declared the production of electronic waste (e-waste) to be a growing global environmental health problem [1–5]. In 2005, annual e-waste generation was estimated at 35 million tons, and increasing, with greater production occurring in developed countries, for later transfer to low- and middle-income countries for reuse or recycling [6].

E-waste is defined as discarded, nonworking electronic products – e.g., cell phones, computers, home appliances, etc. – and their components, which are no longer considered useful by the owner or manufacturer [7]. They are a source of hazardous constituents, such as heavy metals, but also valuable materials, including copper, gold, silver, and rare earth metals [1]. There are formal and informal markets for the recovery of these valuable materials [2]. Around 12 to 35% of all e-waste generated in 2014 was recycled formally in developed countries [7]. Formal recycling facilities often incorporate safety measures for workers [2]. On the other hand, the majority of e-waste recycling in developing countries is informal, representing the main source of income for an increasing number of people, including children, who recycle e-waste without formal training or protective equipment [2,8].

Recycling in these conditions creates risks to human health and the environment, which have raised concerns among the scientific community and governmental agencies [1,2,5]. Human exposure to e-waste pollutants can be occupational or environmental, can affect workers and the general population, and can include vulnerable populations such as children and pregnant women living in or near unregulated recycling sites [2,3]. These exposures have been linked with a range of health effects, including impacts on thyroid function, changes in cellular expression, adverse neonatal effects, decreased lung function, and other adverse effects [3].

Health impacts associated with e-waste recycling have been described worldwide [2]. Studies focusing mainly on informal recyclers have been conducted in lower income countries such as China (Chen et al., 2015; Zheng et al., 2013), Ghana [12,13] and Vietnam [14], and have found high levels of endocrine disruptors and heavy metals in samples of hair, urine and blood [2]. In China, these contaminants have been found at high levels in the surrounding population, in samples from human placenta, breast milk, and blood [15–18]. On the other hand, among formal recyclers in higher income countries, high levels of heavy metals have been reported in blood, urine, skin and clothing in workers in France [19], Sweden [20] and the United States [21]. In summary, several studies have investigated exposures for informal e-waste workers from low-income countries in Asia and Africa; however, little is known about these exposures in middle- and high-income countries outside the United States and Europe. Very little is known in Latin America, with the exception of a study in Uruguay in a pediatric population [22].

The current study is part of a multi-country study (Chile and Thailand) that aims to identify occupational and environmental health hazards associated with informal e-waste recycling, and to identify potential interventions to improve health and reduce the impacts of e-waste recycling. As of 2017, Chile had a population of over 17 million inhabitants, and was highly urbanized: 87% of the population lived in urban areas, and 41% lived in the Metropolitan Region of Santiago [23]. Gross domestic product (GDP) has substantially increased in the past fifteen years, reaching USD$247,028 billion in 2016 [24], promoted by a neoliberal, market economy [25,26]. The model has positioned Chile as one of the most economically developed countries in the region, entering the Organization for Economic Cooperation and Development (OECD), but also the one of the most unequal, with a Gini coefficient of 0.50 by 2011 [27]. Chile's accelerated growth has boost the technological sector, and because of this the has the highest *per capita* production of e-waste in Latin America: 9.9 kg per person a year [28]. Since 2016, e-waste in Chile has been dealt within the recycling Law N° 20.920, which addresses certified and formal recycling companies, and includes Extended Producer Responsibility (EPR) requirements [28,29].

Despite the presence of legislation addressing e-waste recycling, informal recyclers operate in the country, though the extent of their operations is unknown. The informal recycling network usually includes collectors, who collect e-waste from residential areas and sometimes companies; recyclers, who dismantle e-waste products into their constituent parts and recover valuable materials; scrap dealers, who buy raw materials and products from recyclers and collectors; and repair shops, which use parts salvaged by recyclers to repair the broken goods in order to return waste electronics to working condition or transferring functional components to other products.

The purpose of this article is to describe the design and population characteristics of a group of Chilean e-waste workers. Chile, has recently been classified as a high-income country [24], but the extent and methods of informal e-waste recycling in the country is poorly understood. In addition to describing informal e-waste recycling efforts in Chile, we compare formal and informal workers in the country, and also make comparisons to e-waste recycling in other countries.

2. Methods

The original study protocol was approved by Health Sciences and Behavioral Sciences Institutional Review Board (IRB-HSBS) of the University of Michigan (Study eResearch ID: HUM00114562), and the Chilean section was also approved by the Ethics Committee for Research in Human Beings of the Faculty of Medicine, University of Chile (approval 101-2017).

2.1. Study site and design

We elected to focus on two different urban areas where informal recycling might occur. To increase variability, we included Santiago, the largest city in the country, and Temuco, a mid-size city of about 300,000 inhabitants [23] (Figure 1). Informal recycling social movements were contacted to aid the process and identify areas and individuals for recruitment purposes. To facilitate comparisons with formal workers, we recruited a single formal recycling mid-size company in the country.

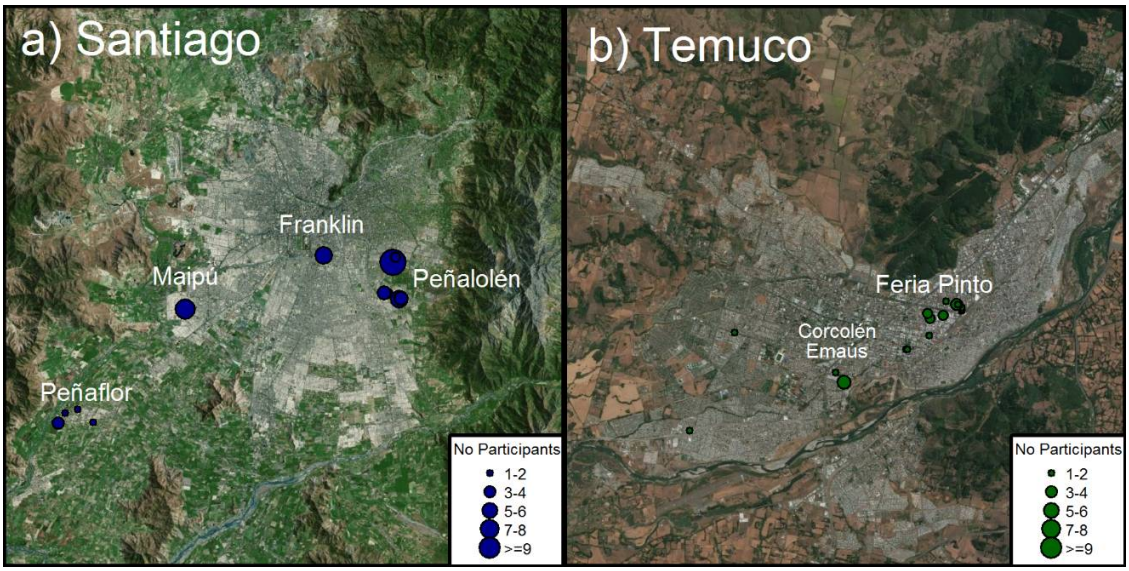

Figure 2. Study site: a) map of Santiago, b) map of Temuco.

2.2. Participant recruitment

During June and July 2017, informal workers were identified in the two cities at e-waste collection sites, repair shops, public fairs, flea markets, and other places previously identified by recycling groups. In July and August, 2017, each of these sites were visited and potential participants were contacted. Potential participants were screened to confirm that they fell into one of the recycling activities targeted in our study (i.e., collectors, recyclers, repair shops, or scrap dealers). Research staff explained the study objectives, procedures, and measurements to potential participants in detail, and interested individuals then signed a Spanish-language consent form.

2.3. Participant activities

Participant data collection in Santiago, Temuco, and at the formal recycling company took place in August 2017. Table 1 summarizes the study procedures completed by all participants with the assistance of research staff. All participants were asked to complete a questionnaire and health assessment, provide blood and urine samples, undergo air sampling and noise monitoring, and complete a daily activity log. This manuscript will focus only on the results from the questionnaires. Four items from the questionnaire were drawn from Cohen's perceived stress scale; these items addressed the frequency with which participants: felt unable to control important things in life; were confident about personal ability to handle problems; felt things were going their way; and felt they could not overcome difficulties [30].

Table 1. Summary of participant activities.

Item	Components
Questionnaire	• Included: Sociodemographic; work history; self-reported health (including physical and mental health); stress; noise exposure; and occupational injuries. • Administered by a trained researcher in Spanish (native speaker). The answers were entered using the Qualtrics Software from University of Michigan.
Health assessment	• Screening questionnaire smoking habits, current respiratory health and exclusion criteria for spirometry. • Weight and height (Portable Balance *Seca* 813 and Portable Stadiometer *Seca* 213, Hamburg, Germany) • Heart rate and blood pressure (Electronic sphygmomanometer OMRON) • Lung-function using forced vital capacity maneuver (Easy One Spirometer, New Diagnostic Design, Andover, MA, USA). • Hearing screenings (portable Earscan 3 audiometer, Earscan, Inc.). • Continuously heart rate during the workday (Polar RS300x watch synced with a Polar H1 heart rate sensing chest strap)
Biomonitoring	• Blood samples. Analyzed for lead, cadmium, manganese, aluminum, nickel, iron, zinc (in whole blood); and copper, calcium, and creatinine (in blood serum) • Urine samples. Analyzed for lead, cadmium, copper, zinc, manganese, iron, nickel, mercury, aluminum, calcium, and creatinine (NIOSH Method 8310)
Exposure assessment	• Air samples in breathing zone of the workers (AirCheck sample pumps attached to a sampling cassette for the collection of lead according to NIOSH Method 7300). Filters analyzed for: antimony, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, molybdenum, nickel, vanadium, and zinc. • Personal noise exposures (Cirrus Dose Badge noise dosimeter). • Surface samples, using a wipe in an area of 10 cm x 10 cm. Analyzed for copper, iron, nickel, manganese, lead, and zinc.
Other procedures	• Photographic records and short videos during the work activities. • Activity log reporting the amount of time spent in each of worker's daily activities. • Focus groups

Additionally, a subset of participants also provided surface wipe samples in their homes or workplaces, were filmed for later activity analysis, and participated in focus groups designed to explore particular aspects of informal e-waste recycling. These activities will also be described elsewhere

2.4. Data Analysis

Only results of the questionnaire are provided in this article. An initial exploratory analysis was performed to identify, and correct, typing errors and missing values. Then, descriptive analysis of the variables was carried out using absolute and relative frequencies, for categorical variables, and measures of central tendency and dispersion, for continuous ones. Differences between sites and types of recyclers were explored using χ^2 and ANOVA.

3. Results

3.1. Sociodemographic and occupational characteristics of the population

From the initial 190 people invited, 93 agreed to participate: 53 informal recyclers in Santiago, 25 informal recyclers in Temuco, and 15 workers at the formal recycling company (Figure 1). In Santiago, participants were mainly clustered around 4 sites: *Peñalolén*, *Peñaflor*, *Maipú* and *Persa Bío-Bío*, with participants from *Peñalolén*, *Peñaflor* and *Maipú* being mostly collectors and recyclers, and those from *Persa Bío-Bío* being mostly repairers. In Temuco, participants were clustered around 3 sites: *Feria Pinto*, *Corcolén Park* and *Emmaus*, with participants from Feria Pinto and Emmaus being mostly repairers, and those at *Corcolén* being recyclers. The 15 participants from the formal recycling plant were mostly operators, with some administrative staff, working in all sections of the recycling process (sorting, dismantling, shredding, packaging, shipping).

Sociodemographic characteristics of the participants are shown in Table 2 and Table S 1. Most participants (74%) were male, with an average age of about 46 years old, and lived in households of about 4 people. About half of the participants were married with children. Their education level included primarily basic (8 years) or medium school (12 years); only 16% reached higher college or technical degrees. Informal workers were slightly more likely to be male, and were slightly older than formal workers. E-waste recycling was the main source of income for most participants (83%), although over a third of participants (37%) reported other sources of income, as well. Monthly income was around USD$500, which is above the minimum salary in Chile (USD$445 per month). More than 20% of participants reported income above USD$1000. Notably, there was no difference in reported income between formal and informal workers. Overall, participants had low- to medium-income and were similar to workers in other technical jobs in Chile [31].

Regarding their work history (Table 3 and Table S 2), most participants were currently employed (97%) and working in e-waste related jobs (99%), although only 65% of them reported e-waste as their main source of income. They have been involved in e-waste activities for ~12 years on average, and most (61%) worked 5-8 hours per day an average of almost 6 days each week. The most commonly reported e-waste activities were recycling (62%), collecting (34%), repairing (31%), and dealing scrap (25%). Also, participants identified their role in the e-waste process mainly as recyclers (46%), collectors (42%), working in repair shops (34%), and buying raw material (10%). When comparing formal and informal workers (Table S 2), it is evident that formal workers worked mainly in direct recycling activities, had e-waste work as their main source of income, and had been working in this sector for a shorter time (less than 2 years on average).

Peer-reviewed version available at Int. J. Environ. Res. Public Health 2019, 16, 386; doi:10.3390/ijerph16030386

Table 2. Sociodemographic characteristics of the study population.

Group	n (%) or mean ± sd
Demographics	
Participants	93 (100%)
Sex (% male)	69 (74%)
Age	47 ± 14
Marital status	
Married	41 (44%)
Single	37 (40%)
Living with partner	8 (8.6%)
Separated	4 (4.3%)
Divorced	2 (2.2%)
Widowed	1 (1.1%)
Family members*	3.8 ± 1.8
Children under 21 years old	45 (48%)
Level of school	
None	7 (7.5%)
Basic school (8 years)	30 (32%)
Medium school (12 years)	41 (44%)
College or higher	15 (16%)
Socioeconomic	
Main sources of income**	
Electric or electronic waste	77 (83%)
Other types of waste	34 (37%)
Other	20 (26%)
Monthly income†	
Less than $165	4 (4%)
$167 - 495	28 (30%)
$497 - 1,156	35 (38%)
$1,156 - 1,651	15 (16%)
More than $1,651	5 (5%)
Prefer not to answer	6 (7%)

* Supported by household income. †Parity of 606 Chilean pesos per dollar by 04/04/18. ** There could be more than one main source of income.

Table 3. Work history and recycling activities.

Group	n (%) or mean ± sd
Currently employed	90 (97%)
Currently involved in e-waste activities	92 (99%)
E-waste as main source of income	60 (65%)
Years working with e-waste	12.4 ± 11.8
Hours of work per day	
Less than 5 hours	4 (4.3%)
5-8 hours	56 (61%)
More than 8 hours	32 (35%)
Work days per week	5.8 ± 1.0
Current job(s)*	
Electric or electronic waste recycling	58 (62%)
Electronics collection	32 (34%)
Electronics repairer	29 (31%)
Scrap dealer	23 (25%)
Trading	5 (5.4%)
Retired	5 (5.4%)
Other	28 (30%)
Role in e-waste recycling	
Recyclers	43 (46%)
Collectors	39 (42%)
Repair shop	32 (34%)
Raw materials buyer	9 (9.7%)

* Multiple choices allowed.

3.2. *Self-reported health*

Results for self-reported health history are shown in Table 4 and Table S 3. Overall, most participants (>60) assessed their health status as good or better, with a small fraction (~30%) reporting fair or poor health. Regarding symptoms in last two weeks, the most commonly reported conditions (with >20% reporting occasionally or frequently experiencing these conditions) were headache or dizziness, heart beating abnormally, breathing problems, and nausea or stomach ache. A small fraction of the participants (~5%) reported more serious symptoms such as blood in urine and blood in stool. Only a fraction of the workers (~30%) sought medical treatment for these conditions, mostly in the formal health care system.

Table 4. Self-reported health history of the study population.

Variable	**n (%)**	**n (%)**
Overall health		
Excellent		3 (3.2%)
Very good		10 (11%)
Good		45 (48%)
Fair		30 (32%)
Poor		5 (5.4%)
Symptoms in last two weeks**	Occasionally	Always or frequently
Headache or dizziness	35 (38%)	9 (9.7%)
Heart beating abnormally	25 (27%)	3 (3.2%)
Breathing problems	19 (20%)	4 (4.3%)
Nausea or stomach ache	18 (19%)	4 (4.3%)
Skin rashes	10 (11%)	5 (5.4%)
Loose or watery stools	10 (11%)	4 (4.3%)
Fever	8 (8.6%)	1 (1.1%)
Shaking or tremors	5 (5.4%)	1 (1.1%)
Blood in urine	2 (2.2%)	1 (1.1%)
Blood in stool	1 (1.1%)	1 (1.1%)
Sought medical care/treatment†		27 (29%)
Type of medical care		
Clinic/hospital		25 (89%)
Traditional medicine		1 (3.6%)
N/A		1 (3.6%)
Other		1 (3.6%)
Current smoker		29 (31%)
Chronic diseases		
None		47 (51%)
High blood pressure		24 (26%)
Diabetes Mellitus		13 (14%)
Asthma		5 (5.4%)
Heart disease		5 (5.4%)
Stroke		4 (4.3%)
Kidney disease		3 (3.2%)
Liver disease		1 (1.1%)
Other		18 (19%)
Taking medication for any of these conditions		29 (63%)
Health problems that limit work		15 (16%)
Unintentional weight loss last year		21 (22%)

*Have you smoked at least 100 cigarettes during your entire life? ** Allowed options were rarely or never, occasionally, and always or frequently. †One participant answered "Don't know" (1.1%)

Regarding chronic conditions, 31% of participants were current smokers (31%), consistent with the national prevalence of smoking in Chile (33.3%) [32]. Most participants did not report chronic diseases. Among those who did, the most common were high blood pressure (26%), diabetes mellitus (14%) and asthma (5.4%). Medication use was common among participants with these conditions. A small fraction of participants (16%) reported that they suffer

conditions that limit their work (16%), and a surprisingly high amount (22%) reported unintentionally weight loss during the past year. When comparing formal and informal workers (Table S 3), no major differences were found.

3.3. Self-reported occupational exposures

Regarding stressors (Table 5 and Table S 4), about 40% of participants felt they were sometimes or very often unable to control important matters in their lives and that they could not overcome difficulties. Insufficient income to support themselves and their families was also reported by 62% of participants. On the other hand, most workers reported that they decide their work methods (77%), they have not experienced violence or harassment at work (83%) and they reported that work do not interfere with their family responsibilities or leisure time (62%). When comparing formal and informal workers (Table S 4), in general no major differences were found.

Table 5. Self-report occupational stressors exposure in the study population.

Stressors	**n (%)**		
	Never/Almost never	Sometimes	Fairly often/Very often
In the last month, how often have you felt:			
Unable to control important things in life*	54 (58%)	27 (29%)	12 (13.2%)
Confident about personal ability to handle problems*	8 (8.6%)	7 (7.5%)	78 (84%)
Things were going your way*	8 (8.6%)	31 (33.3%)	54 (58%)
Could not overcome difficulties*	55 (59%)	29 (31.2%)	9 (9.7%)
Someone else decide work methods/pace/order	72 (77%)	11 (12%)	10 (11%)
Experience violence or harassment at work**	77 (83%)	11 (12%)	4 (4.3%)
Work interfere with family responsibilities/leisure time	58 (62%)	23 (25%)	12 (13%)
Income is not sufficient to support family	38 (41%)	29 (31%)	29 (31%)

*Items drawn from Cohen's perceived stress scale **One participant answered "Prefer not to answer" (1(1.1%))

Self-reported exposure to noise is shown in Table 6. A majority (55%) of participants reported working in loud noise sometimes or more often than sometimes, with an average duration of 8.8 ± 11 years. A number of participants reported difficulty hearing (28%) that had started in adulthood (89%). Diagnosis of hearing loss was rare among workers (8.6%). Finally, nearly one-third of workers reported experiencing tinnitus after being exposed to loud noise. Informal workers (~12 years) had been longer exposed to noise than formals (3.6 years) (Table S 5).

Table 6. Self-report noise exposure in the study population.

Variable	**n (%) or media ± sd**
Exposed to loud noise at work	
- Never	21 (23%)
- Almost never	17 (18%)
- Sometimes	26 (28%)
- Fairly often	16 (17%)
- Very often	13 (14%)
Years working in loud noise	8.8 ± 11
Experienced difficulties hearing	26 (28%)
Time with difficulties hearing	
- Since childhood	2 (7.7%)
- Since adolescence	1 (3.8%)
- Since adulthood	23 (89%)
Diagnosed with hearing loss	8 (8.6%)
Experienced tinnitus after spending time in loud noise	
- Never	48 (52%)
- Almost never	14 (15%)
- Sometimes	25 (27%)
- Fairly often	4 (4.3%)
- Very often	2 (2.2%)

3.4. Self-reported occupational injuries

Participants reported an average of 3 ± 7.1 occupational injuries in the past six months (Table 7 and Table S 6). Frequently reported injury types included cuts and lacerations (31%), contusions and abrasions (16%), and puncture wounds (8.6%), with these injuries primarily occurring to workers' hands (38%) and feet or lower legs (16%). Most participants did not receive formal medical care to treat their wounds (69%) while a small fraction (14%) received treatment at a hospital or clinic. While most workers did not miss work due to injuries (76%), among those who did miss work, 35% lost five or more days. The most frequent activities at the time of injury were dismantling (32%), sorting (16%) and collecting (8.6%) e-waste.

Table 7. Self-report injuries in the study population.

Variable	n (%) or mean ± sd
Injuries in e-waste recycling work in past 6 months	3.0 ± 7.1
For the worst injury during e-waste recycling work:	
Type of injury	
Cuts/lacerations	29 (31%)
Contusions/abrasions	15 (16%)
Punctured wounds	8 (8.6%)
Sprains/strains	4 (4.3%)
Burns/scalds	3 (3.2%)
Fractures	1 (1.1%)
Other	18 (19%)
Body part(s) injured	
Hand	35 (38%)
Foot/lower leg	15 (16%)
Hip	4 (4.3%)
Other	18 (19%)
Medical care received	
Self-administered first aid	28 (40%)
No medical care	20 (29%)
Treatment at hospital/clinic	10 (14%)
Other	12 (17%)
Missed work due to injury	
Did not miss any work and worked regular job	53 (76%)
Did not miss any work and could not do regular job	3 (4.3%)
Missed work	14 (20%)
Working days lost	
Less than 1 day	1 (7.1%)
1-5 days	3 (21%)
5-7 days	3 (21%)
More than 7 days	2 (14%)
Activity at the time of injury	
Dismantling electronic equipment	30 (32%)
Sorting electronic waste	15 (16%)
Collecting electronic waste	8 (8.6%)
Removing covering of wires	2 (2.2%)
Burning activities	0 (0%)
Ash/wire collection after burning	0 (0%)
Other	24 (26%)
Reported tools/parts of work lead to more frequent injuries	55 (59%)
Reported job tasks that have led to more injuries	49 (53%)
Report instructions/training prior to injury	12 (17%)
Use of safety equipment at work	
Leather/rubber gloves	53 (57%)
Rubber-soled boots or shoes	46 (50%)
Safety glasses/face shields/eye protection	33 (36%)
Dust mask	15 (16%)
Latex/plastic gloves	11 (12%)
Earplugs or earmuffs	8 (8.6%)

Other	18 (19%)
Report pain in hands or wrists after working with e-waste	47 (51%)
Intensity of pain in hands/wrists (VAS 0-10)	4.9 ± 2.0
Report muscle soreness in body from sitting in the same position	57 (61%)
Intensity of muscle soreness (VAS 0-10)	5.0 ± 2.2

VAS: Visual Analogous Scale

Most participants reported tools and components (59%) or work tasks (53%) that led to their injuries. Only 17% of participants reported receiving instruction or training on how to prevent injuries (17%). The use of safety equipment was relatively rare. While 57% of workers reported wearing leather/rubber gloves (57%) and 50% reported wearing rubber-soled boots or shoes, only about one-third wore safety glasses or a face shield, and only 16% wore a dust mask. Finally, most participants (51%) reported moderate pain (Visual Analogous Scale-VAS 4.9 ± 2.0) in their hands or wrists after working with e-waste. Similar results were found for reported muscle soreness from sitting in the same position. When comparing formal and informal workers (Table S 6) we found that formal workers reported less injuries that resulted in formal medical care at a hospital or clinic.

4. Discussion

While a number of studies of informal e-waste recycling workers have been conducted worldwide [2], little is known about this industry in middle- and high-income countries outside United States and Europe. Our study of 93 workers appears to be the first study of informal e-waste recyclers in Chile, and adds to the very sparse literature on informal e-waste recycling in Latin America [22]. The participating informal e-waste recycling workers had worked in this sector for more than a decade on average, suggesting that this industry has emerged relatively recently in Chile. Workers generally reported good health status; the prevalence of chronic diseases reported was similar to the national prevalence. Workers reported a number of stressors, and insufficient income to support themselves and their families was a common issue among participants. The prevalence of injuries was high (an average of 3 injuries in the past 6 months), and the use of protective equipment was generally low. The most common injuries were cuts and lacerations to the hands that occurred during the dismantling of e-waste products. A majority of workers reported being exposed to high levels of noise sometimes or more often than sometimes, experiencing pain in their hands after e-waste recycling work, and experiencing muscle soreness after e-waste recycling work. We found no major differences between informal and formal recycling workers, although the participating formal workers were slightly younger, more likely to work mainly as recyclers, and had less experience working with e-waste than did the informal recycling workers.

Studies of informal e-waste recycling workers have been conducted in Ghana (Carlson, 2016; Srigboh et al., 2016; Burns, Sun, Fobil, & Neitzel, 2016) China (Chen et al., 2015; Zheng et al., 2013), Vietnam [14], and India [4]. As with our study, these workers were mostly male, except in Vietnam; however, workers in other studies were generally less educated, younger, and had a lower income and longer and more unstable working hours. Workers in Ghana appeared to [33] to work in e-waste recycling for less time than Chilean workers. E-waste recycling activities reported by informal workers in other countries included mainly collecting, dismantling, and scraping, while in Chile there was also a high prevalence of repairing and reselling e-waste. Health effects and behaviors also differed between our sample and those conducted on informal e-waste recycling workers outside Chile. One study conducted in Ghana [33] suggests that e-waste recycling workers there smoke less in comparison to our sample, but report more cardiovascular symptoms. No studies were found related to the health assessment. The informal workers in our study reported a range of symptoms that are generally consistent with one study noting that informal e-waste recycling work is associated with diseases in the skin, stomach, respiratory tract and other organs [4].

Studies of formal e-waste recycling workers are uncommon. A handful of such studies have been conducted in the USA [21], France [19], and Sweden [20], but only the one in Sweden characterized its population. Formal e-waste recycling workers in Chile were mainly involved in recycling activities such as sorting, scraping, dismantling, and

baling, similar to the process described in other studies of formal workers (Ceballos et al., 2017; Lecler et al., 2015; Julander et al., 2014). None of the other studies among formal e-waste workers had a health assessment similar to ours, so no comparison of health outcomes can be made.

Occupational exposure to stressors among informal e-waste recycling workers has been assessed in Ghana [33], where most participants reported moderate to high levels of stress and work in unfavorable physical conditions, as well as violence or harassment in their occupational environment and insufficient income to support themselves. The Chilean informal e-waste recycling workers addressed here generally did not report substantial exposures to occupational stressors, violence, or harassment. However, our Chilean participants did commonly report insufficient income to support themselves and their families. With regards to occupational noise exposure, Ghanaian informal e-waste recycling workers [33] reported greater intensity of occupational noise exposure, but our Chilean workers reported longer noise exposure times. Difficulty hearing and report of a diagnosis of hearing loss was reported twice as often by our Chilean informal e-waste workers as it was among Ghanaians [33]. We did not identify other studies that quantified occupational injuries among e-waste recycling workers.

There are some limitations in our study that may reduce the generalizability of our findings. First, the representativeness of our sample is unknown, as the workforce of Chilean e-waste recyclers is not well understood, especially in the informal sector. We tried to obtain the most representative sample possible by searching for participants in both informal and formal settings and across several cities in Chile. Second, our finding that workers did not report major health problems may simply be a reflection of the healthy worker effect [35]. Third, our cross-sectional assessment of exposures and health status may not accurately capture changes in these factors that have occurred over time, or the long-term average status. Finally, it is possible that participants' responses were subject to social desirability bias; although most participants reported being unfamiliar with Chilean Law N° 20.920 concerning e-waste recycling [28,29], it is possible that the participants were in fact aware of this law and responded to our questions in ways that maximized their compliance with that law. This could potentially have biased their reporting of injuries, e-waste recycling activity participation, income, etc.

E-waste is a growing global environmental health problem (Heacock et al., 2016; Bakhiyi, Gravel, Ceballos, Flynn, & Zayed, 2018; Lundgren, 2012; Grant et al., 2013; Kiddee, Naidu, & Wong, 2013). With this study we have provided a description of an e-waste recycling population in Latin America, and the first such description in Chile. It appears that the health impacts and exposures to stressors associated with informal e-waste recycling may be lower in Chile than in the developing nations in which similar research has previously been performed. However, our assessment suggests that income insecurity is common among informal Chilean e-waste recyclers, and that injuries are common. These findings indicate that further research of informal e-waste recycling is warranted in Chile.

Supplementary Materials: Table S 7. Sociodemographic characteristics of the study population, by job type and site, Table S 8. Work history and recycling activities, by job type and site, Table S 9. Health characteristics of study population, by job type and site, Table S 10. Self-report of stress in the study population, by job type and site, Table S 11. Self-report noise exposure in the study population, by job type and site, Table S 12. Self-report injuries in the study population, by job type and site

Acknowledgement: This study was funded by the University of Michigan Graham Sustainability Institute. The authors wish to thank the participating workers, without whom this study would not have been possible. The authors are also indebted to the following individuals for their assistance with data collection: Alejandra Parra, Daniela Gonzalez, Aubrey Langeland, Suzanne Chou, Alexandra Clayton, and Liliane Bentley.

Funding: This works has been supported by a grant from the Graham Sustainable Institute of the University of Michigan.

Author Contributions: Richard L. Neitzel is the principal investigator and conceived and designed the study, got the funding acquisition and provided critical revision to the manuscript. Karla Yohannessen, Daniela Pinto-Galleguillos, Denisse Parra and Pablo Ruiz-Rudolph carried out the data collection plan, data analyses, data interpretation, wrote the manuscript, and provided critical revision to the manuscript. Amaranta Agost, Macarena Valdés, Lauren Smith, Katherine Galen and Felipe Rojas are the supervisors and were involved in the data collection plan, data collection and revision to the manuscript.

Conflicts of Interest: No potential conflict of interest was reported by the authors.

5. References

1. Heacock, M.; Kelly, C.B.; Asante, K.A.; Birnbaum, L.S.; Bergman, Å.L.; Bruné, M.-N.; Buka, I.; Carpenter, D.O.; Chen, A.; Huo, X.; Kamel, M.; Landrigan, P.J.; Magalini, F.; Diaz-Barriga, F.; Neira, M.; Omar, M.; Pascale, A.; Ruchirawat, M.; Sly, L.; Sly, P.D.; Van den Berg, M.; Suk, W.A. E-Waste and Harm to Vulnerable Populations: A Growing Global Problem. *Environ. Health Perspect.* **2016**, *124*, 550–555, doi:10.1289/ehp.1509699.
2. Bakhiyi, B.; Gravel, S.; Ceballos, D.; Flynn, M.A.; Zayed, J. Has the question of e-waste opened a Pandora's box? An overview of unpredictable issues and challenges. *Environ. Int.* 2018, *110*, 173–192.
3. Grant, K.; Goldizen, F.C.; Sly, P.D.; Brune, M.N.; Neira, M.; van den Berg, M.; Norman, R.E. Health consequences of exposure to e-waste: A systematic review. *Lancet Glob. Heal.* **2013**, *1*, doi:10.1016/S2214-109X(13)70101-3.
4. Lundgren, K. *The global impact of e-waste: Addressing the challenge*; 2012; ISBN 9789221268970.
5. Kiddee, P.; Naidu, R.; Wong, M.H. Electronic waste management approaches: An overview. *Waste Manag.* **2013**, *33*, 1237–1250, doi:10.1016/j.wasman.2013.01.006.
6. Breivik, K.; Armitage, J.M.; Wania, F.; Jones, K.C. Tracking the Global Generation and Exports of e-Waste. Do Existing Estimates Add up? *Environ. Sci. Technol.* **2014**, *48*, 8735–8743, doi:10.1021/es5021313.
7. Baldé, C.P.; Wang, F.; Kuehr, R.; Huisman, J. *The Global E-Waste Monitor 2014*; 2015; ISBN 9789280845556.
8. Gu, Y.; Wu, Y.; Xu, M.; Wang, H.; Zuo, T. The stability and profitability of the informal WEEE collector in developing countries: A case study of China. *Resour. Conserv. Recycl.* **2016**, *107*, 18–26, doi:10.1016/j.resconrec.2015.12.004.
9. Chen, K.; Zheng, J.; Yan, X.; Yu, L.; Luo, X.; Peng, X.; Yu, Y.; Yang, Z.; Mai, B. Dechlorane Plus in paired hair and serum samples from e-waste workers: Correlation and differences. *Chemosphere* **2015**, *123*, 43–47, doi:10.1016/j.chemosphere.2014.11.058.
10. Zheng, J.; Yan, X.; Chen, S.J.; Peng, X.W.; Hu, G.C.; Chen, K.H.; Luo, X.J.; Mai, B.X.; Yang, Z.Y. Polychlorinated biphenyls in human hair at an e-waste site in China: Composition profiles and chiral signatures in comparison to dust. *Environ. Int.* **2013**, *54*, 128–133, doi:10.1016/j.envint.2013.01.018.
11. Huang, Y.; Ni, W.; Chen, Y.; Wang, X.; Zhang, J.; Wu, K. Levels and risk factors of antimony contamination in human hair from an electronic waste recycling area, Guiyu, China. *Environ. Sci. Pollut. Res.* **2015**, *22*, 7112–7119, doi:10.1007/s11356-014-3941-1.
12. Carlson, K. Electronic Waste Worker Health. In *Proceedings of the Eighth International Conference on Information and Communication Technologies and Development - ICTD '16*; ACM Press: New York, New York, USA, 2016; pp. 1–4.
13. Srigboh, R.K.; Basu, N.; Stephens, J.; Asampong, E.; Perkins, M.; Neitzel, R.L.; Fobil, J. Multiple elemental exposures amongst workers at the Agbogbloshie electronic waste (e-waste) site in Ghana. *Chemosphere* **2016**, *164*, 68–74, doi:10.1016/j.chemosphere.2016.08.089.
14. Eguchi, A.; Nomiyama, K.; Minh Tue, N.; Trang, P.T.K.; Hung Viet, P.; Takahashi, S.; Tanabe, S. Residue profiles of organohalogen compounds in human serum from e-waste recycling sites in North Vietnam: Association with thyroid hormone levels. *Environ. Res.* **2015**, *137*, 440–449, doi:10.1016/j.envres.2015.01.007.
15. Xu, L.; Huo, X.; Zhang, Y.; Li, W.; Zhang, J.; Xu, X. Polybrominated diphenyl ethers in human placenta associated with neonatal physiological development at a typical e-waste recycling area in China. *Environ. Pollut.* **2015**, *196*, 414–422, doi:10.1016/j.envpol.2014.11.002.
16. Xu, L.; Ge, J.; Huo, X.; Zhang, Y.; Lau, A.T.Y.; Xu, X. Differential proteomic expression of human

placenta and fetal development following e-waste lead and cadmium exposure in utero. *Sci. Total Environ.* **2016**, *550*, 1163–1170, doi:10.1016/j.scitotenv.2015.11.084.

17. Li, X.; Tian, Y.; Zhang, Y.; Ben, Y.; Lv, Q. Accumulation of polybrominated diphenyl ethers in breast milk of women from an e-waste recycling center in China. *J. Environ. Sci. (China)* **2017**, *52*, 305–313, doi:10.1016/j.jes.2016.10.008.
18. Lin, X.; Xu, X.; Zeng, X.; Xu, L.; Zeng, Z.; Huo, X. Decreased vaccine antibody titers following exposure to multiple metals and metalloids in e-waste-exposed preschool children. *Environ. Pollut.* **2017**, *220*, 354–363, doi:10.1016/j.envpol.2016.09.071.
19. Lecler, M.-T.; Zimmermann, F.; Silvente, E.; Clerc, F.; Chollot, A.; Grosjean, J. Exposure to hazardous substances in Cathode Ray Tube (CRT) recycling sites in France. *Waste Manag.* **2015**, *39*, 226–235, doi:10.1016/j.wasman.2015.02.027.
20. Julander, A.; Lundgren, L.; Skare, L.; Grander, M.; Palm, B.; Vahter, M.; Liden, C. Formal recycling of e-waste leads to increased exposure to toxic metals: An occupational exposure study from Sweden. *Environ. Int.* **2014**, *73*, 243–251, doi:10.1016/j.envint.2014.07.006.
21. Ceballos, D.; Beaucham, C.; Page, E. Metal exposures at three U.S. electronic scrap recycling facilities. *J. Occup. Environ. Hyg.* **2017**, *14*, 401–408, doi:10.1080/15459624.2016.1269179.
22. Pascale, A.; Sosa, A.; Bares, C.; Battocletti, A.; Moll, M.J.; Pose, D.; Laborde, A.; González, H.; Feola, G. E-Waste Informal Recycling: An Emerging Source of Lead Exposure in South America. *Ann. Glob. Heal.* **2016**, *82*, 197–201, doi:10.1016/j.aogh.2016.01.016.
23. National Statistics Institute 2017 Census results.
24. World Bank Economic data of Chile.
25. Project biography of Chile History of Chile: recent history, neoliberal model.
26. Solimano, A. *Capitalismo a la chilena. Y la prosperidad de las élites*; 2012; ISBN 9789563241426.
27. OECD In it together, why less inequality benefits all in Chile.
28. Magalini, F.; Kuehr, R.; Baldé, C.P. eWaste en América Latina. *eWaste en Am. Lat.* **2015**, 1–38.
29. Alarcón Espinoza, K.S.; Moraga Sariego, P. Gestión y tratamiento jurídico de los residuos de aparatos eléctricos y electrónicos, en el contexto de la regulación genérica de los residuos sólidos en Chile, University of Chile, 2012.
30. Cohen, S.; Kamarck, T.; Mermelstein, R. A Global Measure of Perceived Stress. *J. Health Soc. Behav.* **1983**, *24*, 385–396, doi:10.2307/2136404.
31. Vallebuona, C. *Primera Encuesta Nacional de Condiciones de Empleo, Equidad, Trabajo, Salud y Calidad de Vida de los Trabajadores y Trabajadoras en Chile, ENETS*; 2011;
32. Ministry of Health National health survey 2016-2017, first results.
33. Burns, K.N.; Sun, K.; Fobil, J.N.; Neitzel, R.L. Heart Rate, Stress, and Occupational Noise Exposure among ElectronicWaste Recycling Workers. *Int. J. Environ. Res. Public Health* **2016**, *13*, 1, doi:http://dx.doi.org/10.3390/ijerph13010140.
34. Zheng, J.; Yan, X.; Chen, S.-J.; Peng, X.-W.; Hu, G.-C.; Chen, K.-H.; Luo, X.-J.; Mai, B.-X.; Yang, Z.-Y. Polychlorinated biphenyls in human hair at an e-waste site in China: Composition profiles and chiral signatures in comparison to dust. *Environ. Int.* **2013**, *54*, 128–133, doi:10.1016/j.envint.2013.01.018.
35. Chowdhury, R.; Shah, D.; Payal, A. Healthy worker effect phenomenon: Revisited with emphasis on statistical methods – A review. *Indian J. Occup. Environ. Med.* **2017**, *21*, 2, doi:10.4103/ijoem.IJOEM_53_16.